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Project full name	Brains for Building's Energy Systems
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Use case Dyseco

Towards automatic fault diagnosis under dynamic climate conditions for effective buildings' energy flexibility

Development of a cloud-based data platform for AFDD

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Workpackage(s)	1
Results	2
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SUMMARY

Within the B4B project, DYSECO has specifically contributed to the goal of improving energy inefficiency in climate control systems by detecting faults that lead to more than 25% energy waste. Specifically, participation in B4B has led to significant steps toward a high-quality, globally scalable platform for (i) data storage, (ii) automated data analysis, and (iii) the implementation of machine learning algorithms for automatic fault detection and diagnosis under dynamic climate conditions.

During the project, commercial opportunities and risks were explored, a technical design of the software platform was developed, and the requirements and needs of stakeholders were aligned with them to ensure maximum impact.

In addition to the design of the ultimately intended complete platform, an initial version of the database and dashboard has already been developed and programmed. This was built using Python (Django), the Wagtail CMS platform, and a PostgreSQL database. Data can be uploaded by users, generated by measurement systems, or retrieved via an API. The current platform consists of a database located in the Netherlands, a content management system for configuration and management, and a dashboard for end users. The Stedelijk Museum Amsterdam is the launching customer and provides valuable feedback.

Constructive feedback has been collected for the platform, including from the Cultural Heritage Agency of the Netherlands (RCE) and various building management system suppliers. The feedback suggests that the solution is promising but requires further development before scaling internationally. Key development areas include market diversification beyond the heritage sector (schools, offices, hospitals) and strengthening DYSECO's technical and service capacities in preparation for commercial expansion.

The analysis indicates that the main commercial opportunities lie abroad, particularly for growth in the heritage sector. However, diversification is considered essential and will be explored in parallel with preparations for internationalization. The platform's potential is closely tied to strengthening DYSECO as an existing startup.

The next steps of the project include further development with a professional software developer, exploring strategic partnerships and investments, expanding sales channels, and exploring other sectors. A new research proposal has also been awarded by the RVO (OOK-MB-OPC), in which DYSECO will participate by contributing its expertise in dynamic climate control.

1 INTRODUCTION

More than 25% of the energy used for climate control is lost due to faults in climate control systems. In addition, energy flexibility is limited by typically unnecessarily strict climate conditions. Therefore, DYSECO's goal within the B4B project is to initiate the development of a high-quality, globally scalable platform for (i) data storage, (ii) automated data analysis, and (iii) the implementation of machine learning-based algorithms for Automatic Fault Detection and Diagnosis under dynamic climate conditions.

Fault-free climate control under dynamic conditions is an important foundation for energy flexibility, as it does not rely on maintaining a constant temperature but instead uses strategic variations in temperature—or other parameters—over time. This approach makes climate control much more targeted and allows for the timely detection of faults, which not only saves energy but also improves the climate experience. For example, it can lead to improved thermal comfort in offices or better collection preservation in museums, depending on the purpose for which the climate control system is designed.

Currently, the concept of dynamic climate control has been developed for the heritage sector. This project prepares the DYSECO solution for the implementation of Automatic Fault Diagnosis and includes a market analysis to explore broader applications beyond the niche of museums and archives.

1.1 Dynamic climate conditions

In recent decades, indoor climates have been increasingly tightly conditioned. As a result, energy demand has risen while energy flexibility has decreased. With various domains in mind, the concept of dynamic climate control has been explored to achieve a more efficient approach to climate regulation aimed at energy savings and flexibility.

The concept of dynamic climate control has been researched and developed for more sustainable preventive conservation of our heritage. To achieve this sustainability, two prerequisites are necessary:

- Adequate conditions for temperature and relative humidity to ensure the conservation of collections and buildings, combined with thermal comfort for visitors;
- A climate control system that functions without errors and adheres to the aforementioned conditions.

This prior research was conducted at Eindhoven University of Technology, Faculty of Architecture, in the Building Physics & Systems research group. Over the past 15 years, four PhD studies have been carried out within the Chair of Building Physics for Heritage, all focused on museums and archives. The developments from these studies range from high-quality museum-grade measurement and monitoring to real-time optimization of climate control under dynamic climate conditions. The underlying theory has been published in scientific literature.

The concept has been further developed within the start-up DYSECO (EU and US patents granted) to make the underlying methodology directly applicable in practice. All know-how has been embedded in an algorithm that optimizes indoor temperature and relative humidity in real-time within comfort and conservation requirements, while minimizing energy demand—see Figure 1. This algorithm runs on a controller that communicates with both the building management system and a cloud environment.

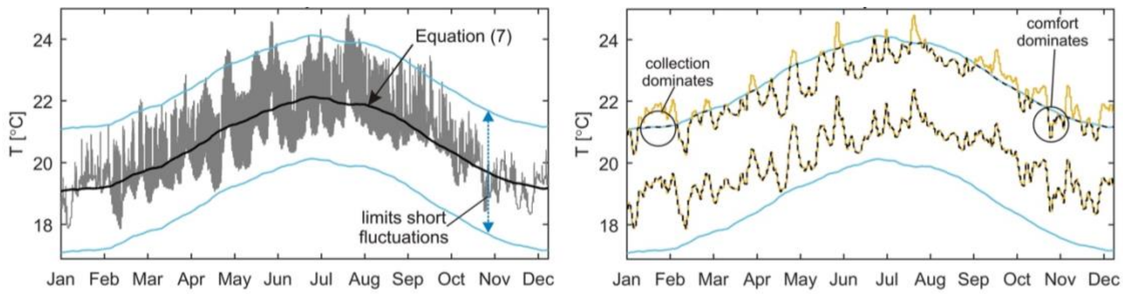


Figure 1. Example of dynamic climate conditions for museums (source: PhD-thesis Kramer, TUE, 2017).

1.2 Multi-dimensional data, Fault Diagnosis and Energy flexibility

A substantial share of the energy demand in the built environment is due to faults in climate systems or their associated controls (~25% energy waste). That's why the RVO MOOI Brains4Buildings project has focused on developing algorithms for Automatic Fault Detection and Diagnosis (AFDD) in energy and climate systems. DYSECO participates in the Brains4Buildings project to ensure that the fault diagnosis development is also aligned with dynamic climate conditions. This is because dynamic climate conditions, in addition to enabling energy savings and health benefits, also allow for a higher degree of energy flexibility: by creating more "leeway" on the indoor climate side through controlled variations, the supply side of the energy system can be used more flexibly.

However, Automatic Fault Diagnosis requires a large volume of reliable measurement data to train machine learning models. Globally, sensor technology has advanced significantly, bringing smart buildings within reach. Yet, the large amount of data is highly segregated across different levels (component, system, building).

1.3 Objective

To truly contribute to the energy transition through energy savings and flexibility—while keeping in mind the primary purpose of climate control, such as comfort, health, and/or collection preservation—an online (cloud) platform is needed that can store multi-dimensional data, automatically analyze it, and detect and diagnose faults under dynamic climate conditions.

This means the platform must be able to communicate with (existing) building management systems to send dynamic setpoints for targeted climate control. DYSECO has developed algorithms for dynamic climate control in the heritage sector, where the algorithms currently run on an add-on controller physically installed in the control cabinet of air handling units, connected to the cloud via a VPN connection. To ensure scalability and applicability to domains beyond the heritage field, a full SaaS solution is proposed, in which no local controllers are required and all functionality is managed in the cloud.

The platform has a modular structure, allowing new functionalities to be easily added via plug-ins. In the B4B project, emphasis is placed on preparing for automatic detection (identifying fault symptoms), then automatic diagnosis (determining the root cause), and "continuous commissioning" (automating maintenance and service tasks).

Platform functionalities:

1) Store data that includes both high-resolution details (e.g., per minute) and long-term periods (up to 10 years). It supports both big data (anonymized project-wide meter data for predictive analytics) and small data (local component-level measurements).
2) Standardized data labeling using formats such as Haystack or Bricks to ensure consistent naming conventions.
3) Preprocessing of measurement data, such as selecting a specific time period, room, parameter, or filtering to office hours only, with associated visualizations.
4) Machine learning for predicting the behavior of the indoor climate and the system. Special attention is given to the application of reinforcement learning, where models begin with limited prior

knowledge and improve over time. This approach is seen as more viable than traditional machine learning that requires historical datasets and engineering expertise for training, as reinforcement learning allows a model trained on Building A to be used as a starting point for Building B.

5) Applying these machine learning models for fault detection: identifying symptoms or anomalies through time series analysis (Step 1).
6) Applying Bayesian Network models for fault diagnosis (Step 2). Step 2 involves using Bayesian Networks to calculate the probability of the underlying fault based on observed symptoms. Though this methodology has been developed at universities in recent years, it has seen little practical application due to the gap between academic research and real-world implementation.
7) Controlling climate systems based on dynamic setpoints for parameters such as temperature. This significantly reduces building energy demand and creates strong potential for energy flexibility.
8) Using weather forecasts to optimize energy flexibility. By proactively accounting for upcoming weather effects, buildings can anticipate heating and cooling demands through load shifting. Especially when combined with dynamic climate control, temperature can be actively managed much more effectively than when using fixed climate requirements over time.

Once the approach has proven effective in the heritage sector, the algorithms can be tailored to other target groups, since the foundation is the same. This will be further investigated through a market study.

2 ACTIVITIES AND RESULTS

2.1 Development and design of the SaaS platform

For the system architecture of the platform, the design developed in WP4 of the B4B project has been adopted—see Figure 2.

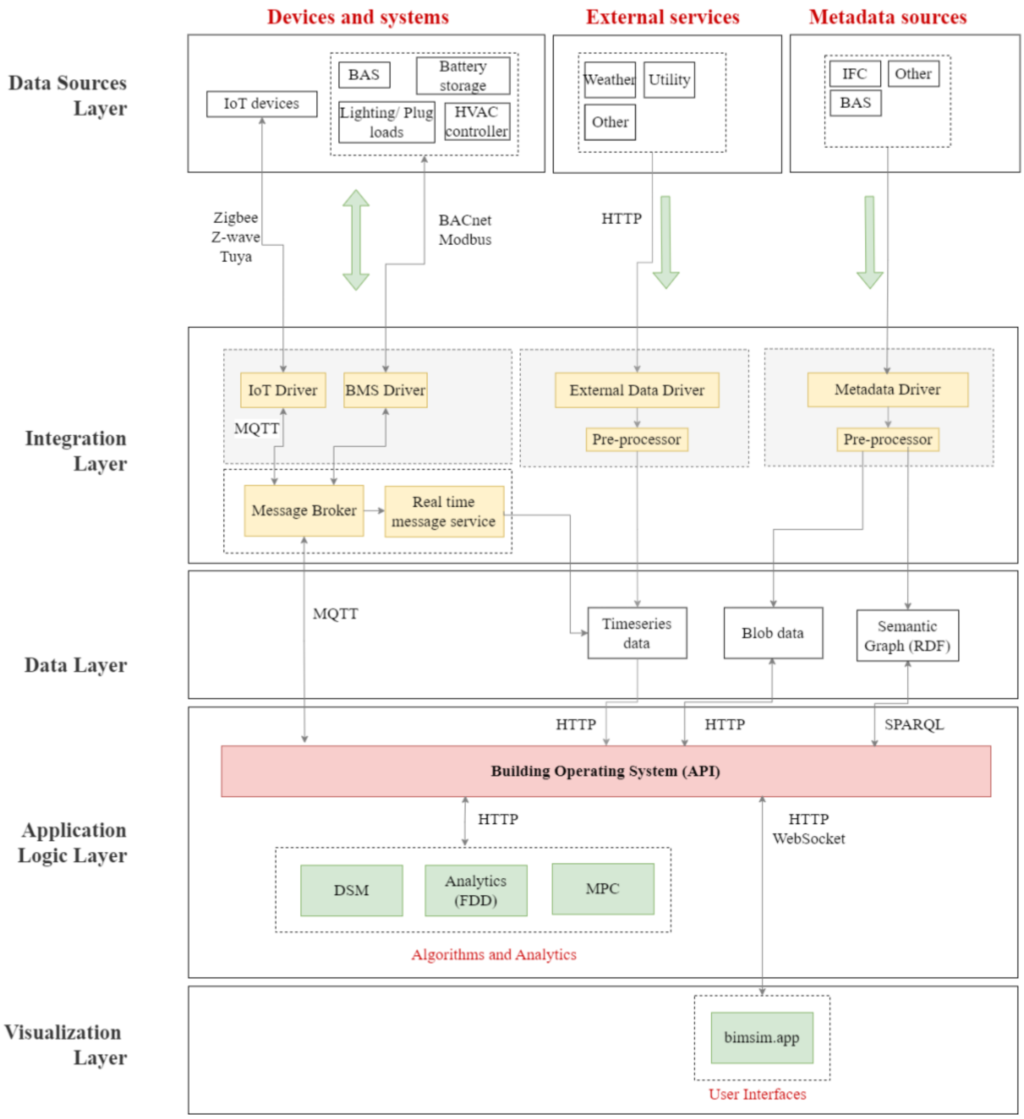


Figure 2. Foundation for the SaaS platform, considering modularity and future functionalities such as Fault Detection and Diagnosis (FDD) and predictive control (MPC).

The beta version of the dashboard has been programmed in Python (Django) and uses the Wagtail CMS platform. The database has been developed using PostgreSQL version 12. This open-source programming language/platform provides a solid foundation, especially considering that it is also used by professional software developers (which is important for future development).

The data can originate from three sources:

1) Files uploaded by the user
   a. Currently in `.xls` format
   b. In the future, support for `.xlsx` and possibly other formats
2) As output from measurement systems
   a. Currently Eltek data files

3) Directly into the database via API
    a. For example, via Modbus
    b. Eltek-formatted text files as daily backups

Backups are made on the server (daily text files), on Surfsara (daily text files), and on another server (database shadow copy).

2.2 Current status of the platform

The current platform includes a database located in the Netherlands, a content management system for configuration and management, and a dashboard for the end customer—see the screenshot below. See *Appendix 1: Developed plots for museums*. for several examples of interactive plots that provide end customers with in-depth insights based on their measurement data.

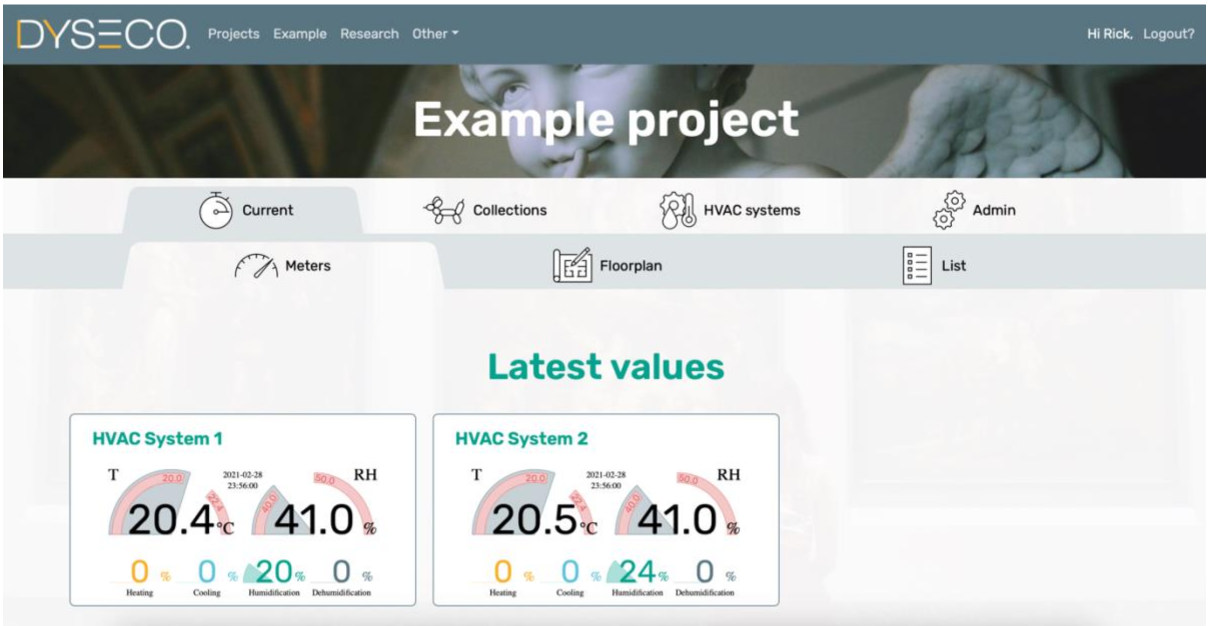


Figure 3. An example project from the dashboard in the new platform (beta version). The tabs show that the platform has been developed for different stakeholders—in this case, facility management, the installer, and collection management.

2.3 Pilot-project and Feedback from customers

The Stedelijk Museum Amsterdam is the first customer of the beta version. This first user was carefully selected, among other things, based on brand recognition, so that they can optimally serve as an ambassador after a successful application. Existing customers of DYSECO will have access to the platform to gather further feedback during its use. End customers within the heritage sector are very enthusiastic about the platform. It provides them with one central platform where their data related to climate control is received, securely stored, and transformed into information via KPIs in the dashboard. A key consideration for scalability is technical management, which is important for further development.

2.4 Analysis opportunities and risks

The results of the opportunities and risk analysis are shown in Table 1.

Table 1. Opportunities and risk analysis.

Opportunities	Strengths to Seize Opportunities	Weaknesses that Make it Difficult
EPBD III system requirements mandatory per 2026	Well-established in the market to handle the 80,000 opportunities that will arise	New entrants to the market putting pressure on existing structures
Lack of expertise for optimal installation settings	Self-learning functionality that automatically applies the optimal settings	Tension between projects and development, making experts not always immediately available
Flexible open structure add-on functionality	Modular structure keeps complexity manageable. Existing control technology is reusable.	AFDD and ML are complex and require a learning curve (partly already completed in the research projects at the TUE)
Congestion issues	Platform creates an energy-flexible system to effectively provide congestion management	Market developments are faster (such as alternative supply/offtake contract forms) than the intended development curve.

Threats	Strengths to Counter the Threats	Weaknesses that Hinder Addressing the Threats
Economic recession due to construction standstill caused by nitrogen issues	Clear added value of the integrated approach of AFDD, ML and Open structure integration GBS platform	Shrinking operating budgets
Low energy prices	Precisely through the focus on energy flexibility, saving through reducing peak load	The payback period of the measures becomes longer
No standardization	Good interaction with end users, possible to establish a de facto open structure standard	Standardization difficult
Complexity	Thorough and experienced project team with in-depth know-how	Project team needs to be expanded. Finding qualified personnel is difficult: AFDD and ML is complex.

3 NEXT STEPS

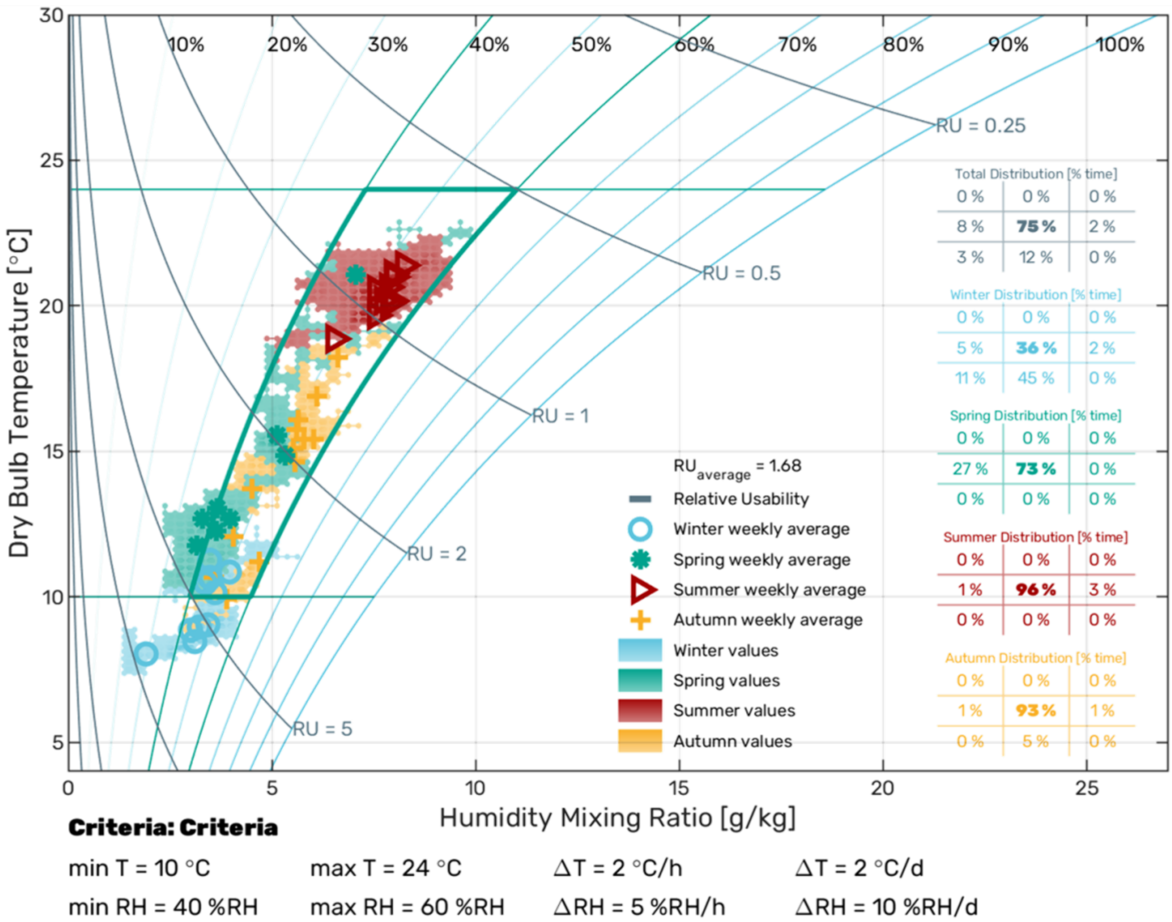
The current platform has been positively received by the heritage sector. Willingness to pay has been demonstrated with the launching customer, the Stedelijk Museum Amsterdam. To ensure scalability and manageability, it has been decided to further develop the beta version of the platform in collaboration with a professional software developer. The first steps in this direction have already been taken.

The new project OOK-MB-OPC has been awarded by RVO, in which TU Eindhoven and TU Delft, together with DYSECO, Kropman, Building G100, and a.s.r. insurance, are working on an open-structure building management system (GBS) suitable for easy integration of innovative plugins developed by third parties (such as Dyseco). Due to the open structure, smart applications, such as the plugins for Automatic Fault Detection and Diagnosis developed in the B4B project, can be easily implemented.

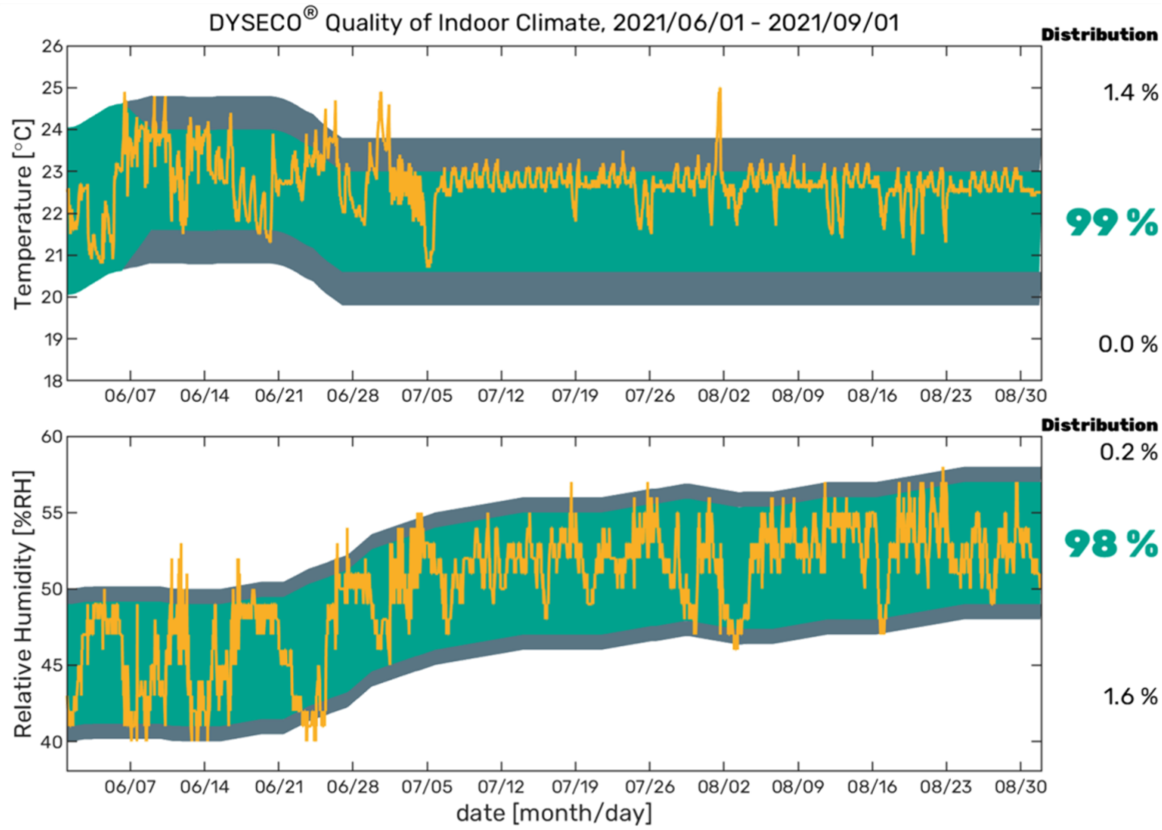
APPENDIX 1: DEVELOPED PLOTS FOR MUSEUMS

In the dashboard, several interactive plots have been developed and implemented to extract maximum insights from the raw measurement data. Some examples are provided below.

The climate evaluation map offers an overview of the key statistics in a single plot, combined for temperature and relative humidity (RH). The deviations are shown per season. The plot has been made interactive, allowing the user to easily select a season.



In the time charts below, the dynamic setpoints are shown, and the percentage of time the indoor climate has met the set requirements is calculated.



Computer models for various mechanisms of collection damage have been integrated into the new platform:

	Schimmel	RB	Dragermateriaal	Decoratieve laag
PAPIER	veilig	1.2	-	-
PANEELSCHILDERIJ	veilig	1.08	schade mogelijk	veilig
MEUBEL	veilig	1.08	veilig	-
HOUTEN BEELD	veilig	1.07	veilig	-